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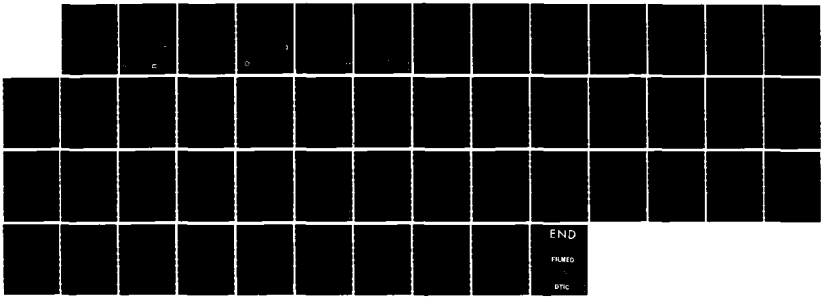

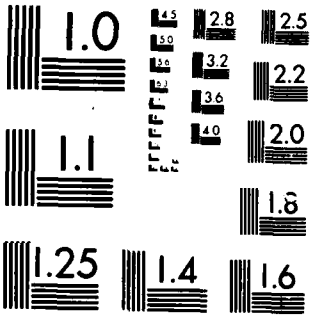

APPLIED MARINE RESEARCH LABORATORY
OLD DOMINION UNIVERSITY
NORFOLK, VIRGINIA

MACROBENTHIC COMMUNITIES OF THE LOWER CHESAPEAKE BAY

By

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Department of Biology
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Final Report
For the period ended June 1, 1984

Prepared for the
Department of the Army
Norfolk District, Corps of Engineers
Fort Norfolk, 803 Front St.
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ABSTRACT

The distribution, abundance, and species composition of subtidal macrobenthic invertebrates of the lower Chesapeake Bay were studied. The macrobenthic infauna was sampled four times per year (seasonally) at 12 sites in 1982 and 1983. Sites were located from the mouth of the Chesapeake Bay along the access channels to the port of Hampton Roads, within the Elizabeth River and up the James River to Mulberry Island. Samples for commercially important benthos were collected at eight locations during the winter and summer cruises of each year. The purpose of this study was: (1) to present recent information concerning the structure of marcobenthic communities of the lower Chespeake Bay, (2) to compare the data generated by this study with data from previous studies of the lower Chesapeake Bay and estuaries along the Southeastern U.S., and (3) to develop multivariate statistical models based upon the baseline data and test the sensitivity of these models to simulated impacted data sets.

From a cluster analysis of the infaunal collection sites, five major site groups were defined. The 12 infaunal collection sites were organized by the cluster analysis into groups that were generally spatially contiguous. This clustering reflected gradients of decreasing average grain size, water depth and salinity that occurred moving up the estuary.

Total community density and indices of species diversity were within the ranges reported in previous studies for comparable sediment types and salinity ranges. The above parameters were lowest at one site near the mouth of the bay and at the site group defined by two sites within the Elizabeth River.

Qualitative samples for commercially important benthic invertebrates (blue crabs, hard shell clams and oysters) confirmed distributional patterns well known to local fishermen and indicated by numerous unpublished surveys of the lower bay.

Multivariate models were developed for each of the site groups. The sensitivity of each type of model was tested using simulated impacted data sets.

INTRODUCTION

The distribution and abundance of the macrobenthic invertebrates of the lower Chesapeake Bay were studied. Density dominants, community abundance, species diversity, and animal-sediment relationships were determined from data from 12 sites extending from the mouth of the Chesapeake Bay, along the access channels to the port of Hampton Roads, into the Elizabeth River and up the James River to Mulberry Island. These sites were part of an environmental study concerning the potential effects of deepening the access channels of the lower Chesapeake Bay. Samples were collected four times per year from January 1982 through October 1983 for the macrobenthic infaunal community and twice per year for commercially important benthic species.

The purpose of this study was: (1) to present recent information concerning the structure of macrobenthic communities of the lower Chesapeake Bay, (2) to compare the data generated by this study with data from previous studies of the lower Chesapeake Bay (Boesch 1973; Dauer et al. 1984; Ewing and Dauer 1982; Hawthorne and Dauer 1983; Tourtellotte and Dauer 1983) and other estuaries of the mid-Atlantic and Southeastern U.S. (Dörjes and Howard 1975; Maurer 1977; Maurer et al. 1978, 1979; Tenore 1972), and (3) to develop multivariate statistical models based upon the baseline data and test the sensitivity of these models to simulated impacted data sets.

Materials and Methods

Field Collection

The macrofauna of the lower Chesapeake Bay was sampled at 12 sites located from the mouth of the bay, along the access channels to the port of Hampton Roads, through the Southern Branch of the Elizabeth River and up the James River to Mulberry Island (Fig. 1). Samples were collected four times per year (seasonally) in January, April, July and October of 1982 and 1983.

All samples for the macrobenthic infaunal community were collected using a Shipek grab (surface area of 0.04 m^2). During the initial cruise in January 1983, 15 Shipek grabs were collected from sites A, C, E, G, I and K (Fig. 1) in order to determine the sample size required for an a priori determined level of precision. Each grab was washed through a 0.5 mm mesh-sized screen, relaxed with dilute isopropyl alcohol, and preserved and stained with a formalin-rose bengal solution.

The number of Shipek grabs necessary to acquire a statistically reliable estimate of the density of individuals was determined using the following formula:

$$N = \left(\frac{ts}{D\bar{x}}\right)^2$$

where: s = standard deviation of the preliminary sample,

t = the tabulated t value at the 0.05 level with the degrees of freedom of the preliminary set of samples

$\bar{x}$ = mean density of the preliminary sample

D = required level of precision expressed as a decimal (Southward 1966)

The product $D\bar{x}$ represents the half width of a desired 95% confidence interval, that is, the distance between the actual mean and the field measured mean with a probability of 0.95. This is a measure of the precision desired in our sampling program. Previous work with benthic organisms has shown that a distance of 30 to 35 percent of the mean will give a statistically reliable estimate (Dauer et al. 1979). With a 30 percent level of precision, an average of 6.2 Shipeks per site would be necessary (range 2.9 to 9.8) and with a 35 percent level of precision and average of 5.8 Shipeks per site would be necessary (range 2.2 to 7.5). Based upon these calculation and considering the manpower available, five Shipeks per site were used to characterize the benthic infaunal community.

At each site a small portion of the surface sediment (8 drams) was retained for sediment analysis. If the sediment from an individual grab changed markedly, an additional sediment sample was taken. Dry sieving of the sand fraction and a pipette analysis of the silt-clay fraction were conducted using the techniques of Folk (1974). Mean particle size, sorting coefficient and percent sand were determined graphically using the formulae of Folk (1974).

At each collection site on each cruise bottom salinity and water depth were determined.

During the January and July cruises of each year commercially important benthic species were sampled from 10 minute tows using a commercial clam dredge at 8 sites shown on Fig.1.

Community Analysis - Dominant Species

All infaunal taxa collected were used in the computation of indices of community structure. Shannon's informational diversity index, Margalef's species richness index, and Pielou's eveness index were calculated (see Ewing and Dauer 1982, for further details).

The 12 collection sites were stratified into biologically determined groups based upon a cluster analysis. In this analysis all species that had a two year mean density greater than 0.5 individuals per grab sample over all sites were included in the analysis (35 species). Taxonomically problematic taxa that could not be accurately identified to the species level were excluded (e.g. Oligochaeta spp. and Cirratulidae spp). The selected species were used in a normal classification analysis of the sites using the Bray-Curtis similarity coefficient and group average sorting on logarithmically transfomed data (Boesch 1977b).

Because some species were collected in very high numbers in only a few sites and/or collection times, dominance of species for the entire study was based upon the biological index ranking (McCloskey 1970). For each cruise the top ten density dominants were scored. The species with the highest density received a score of 10, the species with the second highest density received a score of 9, etc. Rank

density scores were summed over all cruises and all sites within a site group. Only the top 10 species were used in the following analyses.

For each of the top ten density dominants of each site group defined by the cluster analysis the minimum amount of change necessary to produce a statistically significant difference was determined using the following formula (from Sokal and Rohlf 1969 as modified by Michael et al. 1981):

$$\delta = \frac{\left[2s^2(t_{\alpha(v)} + t_{2(1-P)(v)})^2\right]0.5}{n}$$

where:

δ = smallest detectable true difference

s = standard deviation

$t_{\alpha(v)}, t_{2(1-P)(v)}$ = values from a two-tailed t table with v degress of freedom and probabilities of α and $2(1-P)$, respectively

P = desired probability that the difference will be detected

α = desired level of statisitical significance

Multivariate Models

Statistical models were developed and the "sensitivity"

(i.e., the ability of the model to detect changes of known values) of these models to a variety of potential impacts was tested using simulated impacted data sets (SIDS). For further discussion of the rationale of this approach see Alden et al. (1982).

The SIDS were produced by a computer program developed by Dr. R.W. Alden III. For each species used in the analysis the SIDS were generated to have the same frequency distribution as the baseline data, but with different mean values that represented potential impacts. Briefly, the program used a power law transformation to produce the best fit to the baseline data, changed the true mean to a desired mean, and then untransformed the data. Any desired number of replicates could be produced. SIDS were produced with the same auto- and crosscorrelation relationships as the baseline data. For each of the site groups defined by the cluster analysis 6 different SIDS were produced as follows: each species reduced in mean density by 50%, 75%, or 90%; each species increased in mean density by 50%, 100%, or 200%. For each type of impact five impacted data sets were produced.

Stepwise discriminant analysis was used to develop models to test for differences between groups defined a priori. Two groups were defined - one group was one of the cluster analysis site groups while the second group was one of the SIDS. Discriminant analysis produces a multivariate linear additive model that best descriminates between the defined groups. The model is then tested by classifying all

replicates (baseline and SIDS) into one of the two groups, and checking the percentage of correct classifications. The optimal model will classify all replicates from the baseline data into one group and all replicates of the SIDS into the other group (100% correct classification). For sensitivity testing a significant impact was declared to have occurred if greater than 95% of the SIDS replicates were correctly classified.

A second type of model was based upon the approach suggested by Green (1979) for baseline monitoring studies. A principal components analysis was conducted upon each of the site groups defined by the cluster analysis. A principal components analysis produces a multivariate linear additive model with the first principal component accounting for the greatest amount of variance in the data set. The next principal component is independent of the previous one and accounts for the greatest amount of residual variance. This process is continued for all remaining principal components. Green's approach produces a two-dimensional graph based upon the first two principal components. A 95% probability elipse is calculated for standardized principal component scores for the first two principal components. SIDS are next compared to the baseline data and the difference in principal components scores are plotted. If a plotted point lies outside the probabilty ellipse a significant impact is indicated; if within the probability ellipse no impact is indicated.

Results

Site Characteristics

The study sites ranged from moderately sorted medium sands (Site D) to very poorly sorted fine silts (Site J)(Table 1). As expected sediments tended to become finer in grain size and more poorly sorted moving up into the estuary. Salinity and water depth also tended to decrease moving up the estuary (Table 1).

Community Analysis - Dominant Species

A total of 227 taxa were identified. Polychaetes comprised 45.4% (101 species) of the fauna, bivalves 12.3% (28 species), amphipods 11.5% (26 species) and gastropods 11.0% (25 species). See Appendix for a complete listing of the taxa identified.

From the cluster analysis five site groups were defined (Fig. 2). Table 2 shows the major sedimentary and physical-chemical data as averaged over all sites within a site group. In general, proceeding from site group 1 to 5 sediments become finer in grain size and more poorly sorted while salinity and water depth decrease. This pattern reflects primarily the spatial arrangement of the site groups with site group 1 near the mouth of the bay and site groups 4 and 5 farthest up the estuary. Site groups 1-3 form a "sand" grouping with mean particle values in the fine and very fine sand categories. Site groups 4 and 5 form a "mud" grouping with mean particle values in the coarse to fine silt

categories (Table 2).

Table 3A summarizes total community parameters as calculated by the major site groups. Diversity and total community density were lowest in site group 5 which consisted of the two sites in the Elizabeth River.

The density dominants for the five site groups are shown in Tables 4-8.

Commercial Benthos

Table 9 lists the commercially important benthic invertebrates collected from the eight dredge sites (Fig. 1). The results confirm well known patterns of distribution for commercial species of the lower bay as indicated by numerous unpublished studies and information from local fisherman.

The blue crab (Callinectes sapidus) was collected in the open bay collection sites (2 and 3) almost exclusively in winter samples (96.0% of individuals in winter samples only). The open bay collections represent samples of overwintering females that form the basis for the crab dredging industry of the lower bay. The other large collections of blue crabs were in the Elizabeth River sites (6 and 7, Fig. 1) with individuals collected primarily (93.2%) in summer samples.

The hard shell clam (Mercenaria mercenaria) was highly concentrated in dredge sample sites 3-5 (Table 9) again reflecting known distributional patterns for commercially important populations of the species (Mayne et al. 1982).

The highly concentrated distribution of the oyster (Crassostrea virginica) at dredge site 8 corresponds with

collections of "seed bed" populations of the James River (Table 9).

Several species of minor commercial importance were also collected (Table 9). The rock crab (Cancer irroratus) and blue mussel (Mytilus edulis) are much more commercially important farther north along our coast and do not currently represent important resources for the Chesapeake Bay.

Multivariate Models and Sensitivity Analysis

Table 10 shows the results of the sensitivity analysis using the discriminant models. For a given simulated impact the mean percent correct classification is shown. For all site groups an increase of 100-200% in all species would be necessary to declare a significant impact, while only site groups 3 and 4 were very sensitive to large decreases in density.

For all site groups a total defaunation was never declared to be significant (i.e. was always plotted within the 95% probability ellipse). Therefore, the principal components model proved to be insensitive, and unacceptable for future impact assessment. Increases in the range of 500-800% were necessary to indicate a significant impact.

Tables 3-8 also show the minimal detectable impact (as a percent of the mean value) for total community parameters and the dominant species for each site group. For the total community parameters the three species diversity indices are the most sensitive parameters with total community density

being the least sensitive (Table 3). Site groups 1 and 2 would require over 100% change in the mean value before a significant difference could be detected. This basically reflects the higher seasonal variability at these site groups rather than between replicate variation within a season.

An examination of patterns of M.D.I.'s between the site groups shows that site groups 1 and 5 are the least sensitive (or most variable) statistically to changes in mean values of the dominant species (Tables 4-8). The density dominants of these two site groups must change on the average 168.3% and 102.8%, respectively, before a statistically significant difference could be detected. Site group 1 contains a single species and site group 5 four species with M.D.I.'s less than 100%. Site group 4 is the most sensitive with eight species with M.D.I.'s less than 100% (Table 7) and an average M.D.I. of 80.6%. Site groups 2 and 3 are somewhat intermediate in sensitivity with average M.D.I.'s of dominant species of 93.9% and 92.3%, respectively.

DISCUSSION

Comparison with other studies

Dauer et al. (1984) compared recent studies of the macrobenthos of the lower bay (Dauer et al. 1984, Ewing and Dauer 1982; Hawthorne and Dauer 1983; Tourtellotte and Dauer 1983) to studies based on data collected approximately 10 years prior (Boesch 1973, 1977a). Comparisons with prior studies were made difficult by the fact that most of the previous studies in the Chesapeake Bay used a 1.0 mm screen in comparison with the 0.5 mm screen used in the more recent studies. Most of the species that were dominants only in the more recent studies (*Streblospio benedicti*, *Mediomastus ambiseta*, *Amastigos caperatus*, *Tellina agilis*) are mostly smaller sized species (most or all individuals pass through a 1.0 mm screen) whose abundance estimates would be greatly affected by the screen size used in collections.

For the five site groups defined in this study, total community density and indices of species diversity, species richness and eveness were generally high and within the ranges reported for comparable sediment types and salinity ranges (Table 3 of this study compared to studies reviewed in Dauer et al. 1984). The lower densities and indices of species diversity found within the Elizabeth River site group of this study are within the ranges reported in previous studies (Hawthorne and Dauer 1983) and generally reflect the lower diversity and density expected in high silt-clay type

sediments associated with creeks and rivers of limited circulation (Dauer et al. 1984).

There are several species previously reported as dominants that are rare or absent in the more recent studies - Ampelisca vadorum, Heteromastus filiformis, and Nephtys magellanica in sandy habitats; Spiochaetopterus oculatus, Phoronis psammophila and Linopherus ambigua in muddy sediments (see Dauer et al. 1984 for further comparisons). Reduction in the dominance of these species may be due to long term trends of the various species or to major episodic events. Salinity reduction due to Tropical Storm Agnes produced great differences in density of the macrobenthic dominants of the polyhaline region of the James River and Hampton Roads area (Boesch et al. 1976).

The dominant species of this study (Tables 4-8) can be divided into four groups: Group I - species dominant on the inner shelf and sandy sediments of the lower bay, Group II - species dominant in sandy sediments of the lower bay, Group III - species dominant in sandy and muddy sediments, and Group IV - species dominant in muddy sites only.

Group I species were dominants both on inner shelf and sandy sediments of the lower bay and included Spiophanes bombyx, Tellina agilis, Nephtys picta and Polygordius sp. S. bombyx and T. agilis are the most widespread species of this group being reported as dominants of the inner shelf (Table 7, Dauer et al. 1984), a variety of locations in sandy sediments of the open bay (bay-wide transects, clean-sand

site group, Table 3, Dauer et al. 1984; eastern shore, offshore site group, Table 3, Ewing and Dauer, 1982; Lynnhaven Roads site group, Table 6, Tourtellotte and Dauer, 1983) and associated with inlet-shoal sites of lower bay tidal creeks and bays (Table 4, Ewing and Dauer, 1982; Table 3, Tourtellotte and Dauer 1983). N. picta was reported as a dominant in all three sand groups of this study, while Polygordius sp. was a dominant in site groups 1 and 2 of this study.

Group II species were dominant in sandy sediments of the lower bay only and included Ensis directus, Amastigos caperatus and Glycera dibranchiata. Theses species were dominants in site groups 1 and 2 (but not 3) of this study and were also reported as dominants of the clean-sand site group of the open bay study of Dauer et al. (1984). G. dibranchiata was also reported as a dominant species of sand sites off the eastern shore of the bay (Table 3, Ewing and Dauer 1982).

Group III species were found in both sandy and muddy site groups and included Mediomastus ambiseta, Paraprionospio pinnata, Glycinde solitaria and Acteocina canaliculata. M. ambiseta is the most widely distributed species in the lower bay. This species has been reported as a density dominant on the shelf (Dauer et al. 1984), of all site groups except 1 of this study, in numerous locations and sediment types of the open bay (Tables 2 and 4, clean-sand and silty-sand site groups, Dauer et al. 1984; Table 3, offshore site group, Ewing and Dauer 1982; Lynnhaven Roads site group, Table 6,

Tourtellotte and Dauer 1983) and in muddy sites of tidal creeks and small coastal bays (Table 5, Ewing and Dauer 1982; Table 5, Tourtellotte and Dauer 1983). Both A. canaliculata and P. pinnata were previously described by Boesch (1973) as ubiquitous with respect to sediment type in the Hampton Roads area. Both species were reported as dominants in open bay silty-sand sites (Table 4, Dauer et al. 1984) and P. pinnata as a dominant in high silt-clay content sites of the Lynnhaven (Table 5, Tourtellotte and Dauer 1983) and Elizabeth Rivers (Table 4, Hawthorne and Dauer 1983). G. solitaria was a dominant species in the Lynnhaven River system in offshore fine sands and in muddy creek bottoms (Tables 5 and 6, Tourtellotte and Dauer 1983).

Group IV species were dominant only in the high silt-clay sediments of site groups 4 and 5 of this study and include Leucon americanus, Streblospio benedicti, Nereis succinea, Eteone heteropoda and Leitoscoloplos fragilis. All of the polychaetes in this group have been termed "euryhaline opportunists" by Boesch (1977a). All five of the species in this group were previously reported as dominants of the Southern Branch of the Elizabeth River (Table 4, Hawthorne and Dauer 1983). S. benedicti, N. succinea and E. heteropoda were previously reported as dominants of muddy sediments of the eastern shore and Lynnhaven River system (Table 5, Ewing and Dauer 1982; Table 5, Tourtellotte and Dauer 1983).

Comparisons with other estuaries of the mid-Atlantic and Southeastern U.S.A. show broad qualitative similarities.

Boesch's (1977a) estuarine opportunisits are widely distributed along the coast, particularly in silty sediments (Watling 1974; Dörjes and Howard 1975; Maurer 1977; Tenore 1972). The fauna of sandy habitats of the polyhaline regions of Delaware bay (Maurer et al. 1978, 1979), the Pamlico River (Tenore 1972) and Georgia's Ogeechee River (Dorjes and Howard 1975) often are characterized by such species as Spiophanes bombyx, Glycera dibranchiata and Tellina spp. Ensis directus is also a sand species of wide geographic distribution (Maurer et al. 1978, 1979). Nereis succinea is a characteristic species of mesohaline regions (Diaz and Boesch 1977; Dörjes and Howard 1975; Tenore 1972). Macoma balthica was also reported as a dominant species of the mesohaline region of the James River of the Chesapeake Bay (Diaz and Boesch 1977) and in the Pamlico River (Tenore 1972).

Multivariate Models and Sensitivity Analysis

The testing of the sensitivity of various multivariate models developed from the baseline data is useful (1) to indicate the magnitude of change necessary to produce a statistically significant difference and (2) to test if models may be relatively insensitive, and therefore, inappropriate for impact assessment.

The discriminant models produced for the different site groups varied in sensitivity to a variety of simulated impacts (Table 10). For this study 95% or better correct classification of the simulated impacted data sets was

considered to indicate a significant impact. All five site groups were significantly affected by a 200% increase in the density of dominant species, while only site group 3 was sensitive to a 100% increase. With decreasing densities only site groups 3 and 4 were sensitive and only when densities were decreased at least 90%.

The sensitivity patterns shown are probably affected by the size of the site group, and therefore, the number of replicates used to create the discriminant models. Site groups 1 and 5 which were generally the least sensitive consisted of one and two sites, respectively, while site groups 3, 4 and 5 consisted of three sites each (Fig. 2).

Although site groups 3 and 4 showed the greatest overall sensitivity to simulated impacts, this should not be confused with the biological sensitivity of the component species and communities. A greater absolute degradation of the environment at site groups 3 and 4 may be necessary to produce the same relative amount of change in the biota compared to site groups that are less sensitive to statistical changes.

The graphical method of Green (1979), which is based upon a principal components model of the baseline data, was shown to be too insensitive to be useful in impact assessment. A principal components analysis produces models useful for indicating which potential factor(s) might explain or account for the greatest amount of variance in the data set. However, the two-dimensional graphical technique of Green does not declare a total defaunation as being

significant; such a result is ecologically unacceptable. However, without the type of sensitivity testing used in this study this model may have been used in future impact assessment studies. In that case ecologically unacceptable alterations might occur which the model would say were not statistically significant. The necessity of sensitivity testing with simulated impacted data sets is obvious.

SUMMARY

1. The macrobenthic infaunal communities associated with access channels to the port of Hampton roads and the James and Elizabeth Rivers were sampled quantitatively in January, April, July and October of 1982 and 1983 at 12 sites. Commercially important benthic invertebrate species were sampled at eight sites during the January and July cruises of each year.

2. From a cluster analysis of the infaunal collection sites, five major site groups were defined. Each site group was analyzed separately. The original collection sites were organized by the cluster analysis into groups that were generally spatially contiguous. These cluster site groups reflected gradients of decreasing average grain size, water depth and salinity progressing from the mouth of the bay up the estuary.

3. Total community density and indices of species diversity, species richness and eveness were generally high and within the ranges reported in previous studies of the lower bay for comparable sediment types and salinity ranges. The lowest values for these parameters were found at one site near the mouth of the bay and at the site group composed of two sites within the Elizabeth River.

4. The dominant species of all site groups were classified into four species groups based upon their distributions. Group I species were dominants on both the inner continental shelf and sandy sediments near the mouth of

the bay. Group II species were dominants in sandy sediments near the mouth of the bay. Group III species were dominant in both sandy and muddy sediments (ubiquitous species). Group IV species were dominant only in muddy sediments.

5. Qualitative samples for commercially important benthic invertebrate species confirmed well known distributional patterns for blue crabs, hard shell clams and oysters.

6. Multivariate models based upon discriminant and principal components analysis were developed for each site group. The sensitivity of each model was tested using simulated impacted data sets.

7. The minimal amount of change necessary in order to detect a significant difference was calculated for all community parameters (total community density and species diversity indices) and for each density dominant of each site group.

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Table 1. Summary of sedimentary and physical-chemical data for the study sites. A. Sedimentary particle distribution parameters. B. Salinity (in ppt) and water depth. Shown are means for all parameters.

A. Sedimentary Parameters

SITE	MEAN PHI	SORTING COEFFICIENT	% SAND
A	2.44	0.87	95.47
B	3.17	1.29	65.48
C	2.63	0.90	90.04
D	1.80	0.80	94.33
E	3.33	0.74	86.54
F	4.21	1.50	37.60
G	3.08	0.95	77.82
H	4.67	1.49	21.70
I	6.62	3.05	12.27
J	7.17	2.98	6.19
K	5.67	2.79	14.17
L	4.53	1.08	14.78

B. Salinity and Water Depth

SITE	SALINITY (ppt)	DEPTH (m)
A	29.1	14.3
B	29.7	17.9
C	28.1	13.0
D	28.0	11.8
E	25.1	10.1
F	24.5	9.9
G	20.7	5.3
H	19.1	6.7
I	19.0	8.1
J	18.6	13.1
K	17.0	5.3
L	15.7	7.2

Table 2. Summary of sedimentary and physical-chemical data by site groups defined by the cluster analysis.

SITE GROUP	MEAN PHI	SORTING COEFFICIENT	% SAND	SALINITY (ppt)	DEPTH (m)
1	2.44	0.87	95.47	29.1	14.3
2	2.80	1.00	81.95	28.6	14.2
3	3.54	1.06	67.32	23.4	8.4
4	4.96	1.79	16.88	17.3	6.4
5	6.85	2.01	9.23	18.8	10.6

Table 3. Summary of community parameters by site groups (see Fig. 2). A. Shown are means (standard error) for total community density in individuals per m^2, H' - Shannon's diversity index, SR - Margalef's species richness index, and J' - Pielou's eveness index. B. Sensitivity Analysis. Shown are the M.D.I.'s (minimal detectable impact) with coefficients of variation in parentheses.

A. Community Parameters

PARAMETER	SITE GROUP 1	2	3	4	5
Community Density	1,810 (843)	4,485 (893)	2,966 (407)	2,196 (270)	1,571 (228)
H'	3.74 (0.11)	3.18 (0.10)	3.40 (0.10)	3.45 (0.13)	2.24 (0.13)
SR	5.20 (0.35)	5.36 (0.23)	5.41 (0.40)	4.97 (0.32)	2.55 (0.10)
J'	0.80 (0.05)	0.62 (0.02)	0.66 (0.02)	0.71 (0.02)	0.57 (0.03)

B. Sensitivity Analysis

PARAMETER	SITE GROUP 1	2	3	4	5
Community Density	246 (2.95)	103 (2.18)	71 (1.50)	64 (1.35)	75 (1.30)
H'	15 (0.18)	16 (0.34)	16 (0.33)	20 (0.41)	30 (0.51)
SR	35 (0.42)	23 (0.48)	38 (0.81)	34 (0.71)	21 (0.36)
J'	30 (0.36)	17 (0.36)	14 (0.30)	13 (0.28)	28 (0.48)

Table 4. Density dominants of site group 1 (see Fig 2.) based upon density ranking analysis of all stations within a site group over all cruises in 1982 and 1983. Densities are individuals per m^2 (one standard error). Taxon code: A-Amphipod, B-Bivalve, C-Cumacean, G-Gastropod, P-Polychaete, Ph-Phoronid. Maximum Biological Index Value (B.I.V.) equals 80. C.V. is the coefficient of variation. M.D.I. is the minimal detectable impact (see text for further explanation) as a percentage of the mean.

	Species	Density	B.I.V.	C.V.	M.D.I.
1.	Tellina agilis (B)	160 (35)	54.0	1.38	115.1
2.	Nephtys picta (P)	55 (10)	44.5	1.12	93.4
3.	Spiophanes bombyx (P)	130 (37)	41.5	1.80	150.1
4.	Polygordius sp. (P)	73 (31)	33.0	2.66	221.6
5.	Ensis directus (B)	207 (62)	25.5	1.90	158.6
6.	Trichophoxus epistomus (A)	37 (10)	23.3	1.65	137.8
7.	Magelona sp. (P)	29 (6)	22.8	1.35	113.0
8.	Glycera dibranchiata (P)	24 (5)	20.25	1.26	105.5
9.	Synchelidium americanum (A)	19 (6)	17.0	2.02	167.0
10.	Amastigos caperatus (P)	365 (285)	17.0	5.06	422 3

Table 5. Density dominants of site group 2. (See Table 4 for further information). Maximum B.I.V. equals 240.

Species	Density	B.I.V.	C.V.	M.D.I.
1. Tellina agilis (B)	652 (109)	170.5	1.83	86.5
2. Mediomastus ambiseta (P)	469 (75)	166.5	1.74	82.3
3. Amastigos caperatus (P)	784 (196)	153.5	2.74	129.4
4. Polygordius sp. (P)	477 (88)	120.3	2.03	96.1
5. Spiophanes bombyx (P)	190 (35)	116.5	2.01	95.0
6. Ensis directus (B)	478 (102)	67.5	2.34	110.7
7. Apoprionospio pygmaea (P)	106 (28)	37.3	2.86	135.3
8. Aricidea catherinae (P)	25 (4)	24.5	1.85	87.5
9. Nephtys picta (P)	34 (4)	23.7	1.17	55.4
10. Glycera dibranchiata (P)	33 (4)	19.0	1.28	60.9

Table 6. Density dominants of site group 3. (See Table 4 for further information). Maximum B.I.V. equals 240.

Species	Density	B.I.V.	C.V.	M.D.I.
1. *Mediomastus ambiseta* (P)	875 (101)	216.0	1.57	74.3
2. *Acteocina canaliculata* (G)	342 (37)	182.5	1.19	56.4
3. *Paraprionospio pinnata* (P)	163 (23)	98.5	1.56	73.6
4. *Spiophanes bombyx* (P)	118 (20)	77.5	1.86	87.8
5. *Tellina agilis* (B)	67 (7)	73.0	1.19	56.3
6. *Glycinde solitaria* (P)	68 (8)	63.0	1.22	57.7
7. *Phoronis psammophila* (Ph)	91 (31)	54.5	3.73	176.2
8. *Nephtys picta* (P)	29 (4)	41.5	1.68	79.6
9. *Polydora ligni* (P)	216 (74)	34.0	3.75	177.0
10. *Odostomia* sp. (G)	46 (7)	29.0	1.73	81.7

Table 7. Density dominants of site group 4. (See Table 4 for further information). Maximum B.I.V. equals 240.

Species	Density	B.I.V.	C.V.	M.D.I.
1. Paraprionospio pinnata (P)	514 (36)	220.0	0.77	36.6
2. Acteocina canaliculata (G)	366 (45)	184.5	1.34	63.5
3. Glycinde solitaria (P)	132 (8)	131.0	0.67	31.6
4. Mediomastus ambiseta (P)	202 (36)	107.5	1.97	93.3
5. Leucon americanus (C)	118 (17)	99.0	1.54	72.9
6. Phoronis psammophila (Ph)	120 (30)	56.0	2.76	130.5
7. Odostomia sp. (G)	38 (6)	49.5	1.76	82.9
8. Ampelisca abdita (A)	42 (6)	47.3	1.65	77.8
9. Nereis succinea (P)	46 (11)	38.5	2.59	122.6
10. Streblospio benedicti (P)	44 (8)	34.1	2.00	94.4

Table 8. Density dominants of site group 5. (See Table 4 for further information). Maximum B.I.V. equals 160.

	Species	Density	B.I.V.	C.V.	M.D.I.
1.	Streblospio benedicti (P)	646 (92)	151.0	1.27	73.7
2.	Paraprionospio pinnata (P)	324 (39)	115.5	1.06	61.8
3.	Leitoscoloplos fragilis (P)	79 (14)	96.1	1.55	89.7
4.	Leucon americanus (C)	29 (6)	52.9	1.73	100.0
5.	Acteocina canaliculata (G)	29 (6)	37.9	1.91	110.0
6.	Mediomastus ambiseta (P)	44 (8)	32.5	1.88	108.7
7.	Eteone heteropoda (P)	13 (2)	30.5	1.52	87.9
8.	Glycinde solitaria (P)	27 (6)	28.5	2.13	123.5
9.	Macoma balthica (B)	14 (3)	24.9	2.16	124.9
10.	Polydora ligni (P)	14 (4)	24.2	2.56	147.9

Table 9. Summary of the spatial distribution of commercially important benthic species. Shown are the total numbers of individuals collected in four 10 minute trawls of a clam dredge (January and July cruises of 1982 and 1983). A. Major commercial species. B. Minor commercial species.

A. Major Commercial Species

	Collection Site							
Species	1	2	3	4	5	6	7	8
Callinectes sapidus	-	13	12	1	5	13	31	-
Mercenaria mercenaria	-	-	25	6	33	-	-	2
Crassostrea virginica	-	-	-	-	3	-	-	81

B. Minor Commercial Species

	Collection Site							
Species	1	2	3	4	5	6	7	8
Cancer irroratus	8	7	4	-	-	-	-	-
Mytilus edulis	-	100	750	300	-	-	-	-

Table 10. Summary of sensitivity analysis of discriminant models based upon baseline data and simulated impacted data sets. Shown are the average percent correct classification of the simulated impacted data sets. Each percent shown is the average of 5 simulated impacted data sets.

Simulated Impact	1	2	3	4	5
200% increase	96.0	97.3	98.7	97.3	100.0
100% increase	80.0	75.3	96.0	90.7	74.0
50% increase	80.0	64.0	74.7	80.0	72.0
50% decrease	84.0	85.3	93.3	81.3	86.0
75% decrease	80.0	86.7	92.0	85.3	88.0
90% decrease	88.8	84.0	94.7	94.7	88.0

Figure 1. Location of benthic collection sites. Letters indicate infaunal collection sites and numbers indicate clam dredge sites.

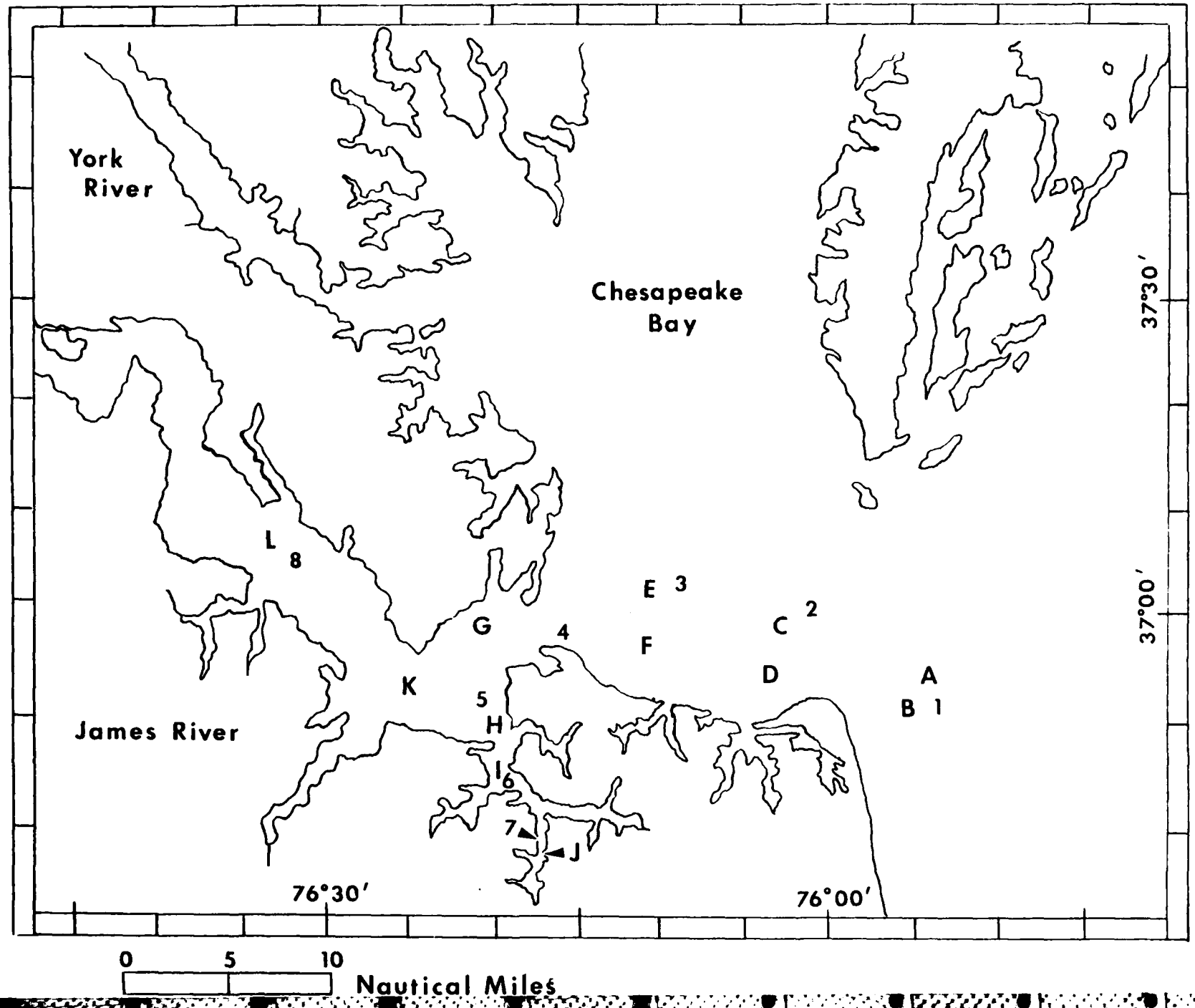
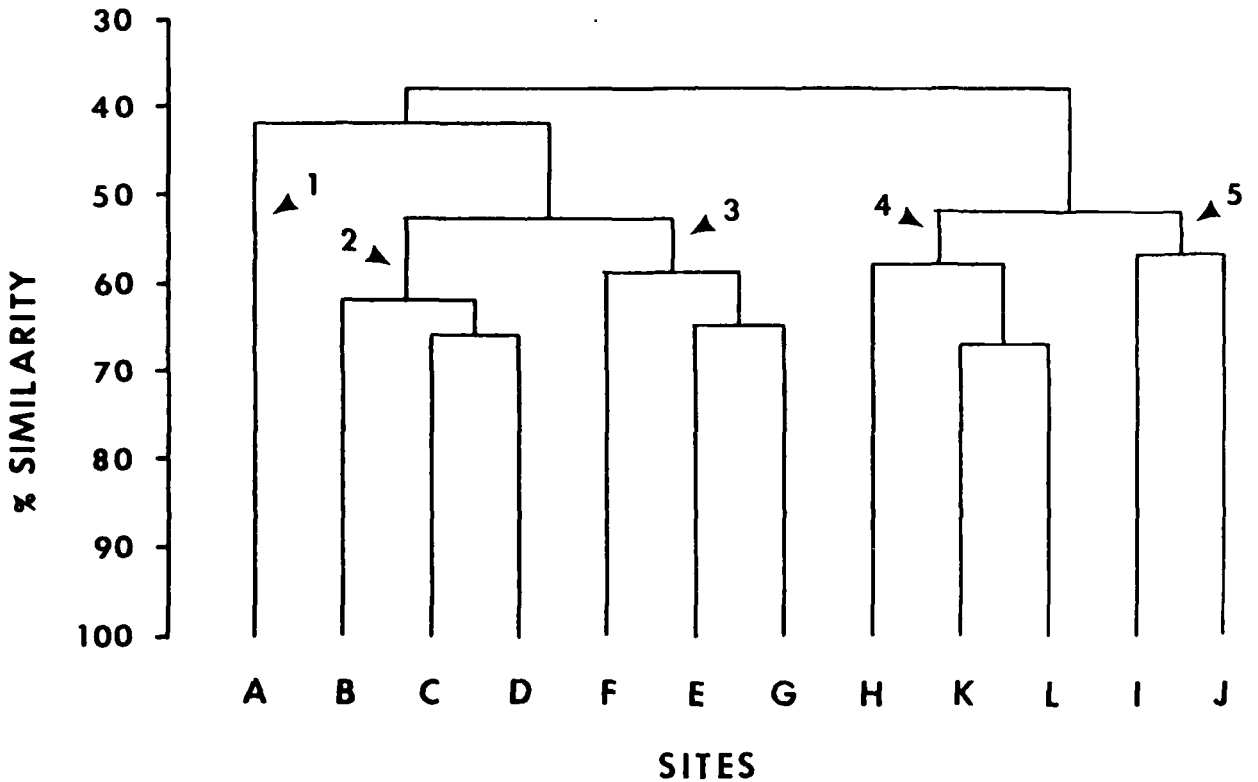

York River
Chesapeake Bay
James River
37°30′
37°00′
76°30′
76°00′
A
B 1
C 2
D
E 3
F
G 4
H 5
I 6
J 7
K
L 8
0 5 10
Nautical Miles

Figure 2. Similarity dendrogram of the infaunal collection sites. Major site groups are indicated.


30
40
50
60
70
80
90
100
% SIMILARITY
1
2
3
4
5
A
B
C
D
F
E
G
H
K
L
I
J
SITES

APPENDIX - TAXA COLLECTED DURING STUDY

CNIDARIA : ANTHOZOA
Anthozoa spp.
PLATYHELMINTHES : TURBELLARIA
Turbellaria spp.
NEMERTEA
Nemertea spp.
ANNELIDA : POLYCHAETA
Aglaophamus circinata (Verrill)
Amastigos caperatus Ewing and Dauer
Ampharete arctica Malmgren
Ampharetidae spp.
Ancistrosyllis hartmanae Pettibone
Apoprionospio pygmaea (Hartman)
Aricidea catherinae Laubier
Aricidea wassi Pettibone
Asabellides oculata (Webster)
Asychis elongata (Verrill)
Autolytus spp.
Brania clavata (Claparede)
Brania welfleetensis Pettibone
Capitella capitata (Fabricius)
Capitella spp.
Capitomastus aciculatus Hartman
Cirratulidae spp.
Cirrophorus furcatus (Hartman)
Clymenella torquata (Leidy)
Diapatra cuprea (Bosc)
Drilonereis longa Webster
Drilonereis magna Webster and Benedict
Eteone heteropoda Hartman
Eteone lactea Claparede
Eumida sanguinea (Oersted)
Glycera americana Leidy
Glycera dibranchiata Ehlers
Glycera spp.
Glycinde solitaria (Webster)
Gyptis brevipalpa (Hartmann-Schroder)
Gyptis vittata Webster and Benedict
Harmothoe extenuata (Grube)
Hemipodus roseus Quatrefages
Heteromastus filiformis (Claparede)
Hydroides dianthus Verrill
Leitoscoloplos fragilis (Verrill)
Lepidonotus sublevis Verrill
Loimia medusa (Savigny)
Lumbrineris fragilis (Muller)
Lumbrineris tenuis Verrill
Macroclymene zonalis (Verrill)
Magelona sp.
Maldanidae spp.
Mediomastus ambiseta (Hartman)

Microphthalmus sczelkowii Mecsnikow
Microphthalmus sp.
Micropthalmus similis Bobretsky
Minuspio cirrifera (Wiren)
Nephtyidae spp.
Nephtys incisa Malmgren
Nephtys picta Ehlers
Nereidae spp.
Nereis acuminata Ehlers
Nereis succinea (Frey and Leuckart)
Notomastus hemipodus Hartman
Notomastus latericeus Sars
Onuphidae spp.
Onuphis eremita Audouin and Milne-Edwards
Owenia fusiformis delli Chiaje
Paleanotus heteroseta Hartman
Paradoneis lyra (Southern)
Parahesione luteola (Webster)
Paranaitis speciosa (Webster)
Paraprionospio pinnata (Ehlers)
Pectinaria gouldii (Verrill)
Pherusa sp.
Phyllodoce arenae Webster
Phyllodoce castanea (Marenzeller)
Phyllodocidae spp.
Pista palmata (Verrill)
Podarke obscura Verrill
Polycirrus eximius (Leidy)
Polydora caulleryi Mesnil
Polydora commensalis Andrews
Polydora ligni Webster
Polydora socialis (Shmarda)
Polygordius spp.
Polynoidae sp.
Potamilla neglecta (Sars)
Potamilla reniformis (Linnaeus)
Protodorvillea kefersteini (McIntosh)
Pseudeurythoe ambigua (Fuavel)
Sabellaria vulgaris Verrill
Scalibregma inflatum Rathke
Schistomeringos caeca (Webster and Benedict)
Schistomeringos rudolphi (delle Chiaje)
Scolecolepides viridis (Verrill)
Scolelepis bousfieldi Pettibone
Scolelepis sp.
Scolelepis squamata (Mueller)
Scoloplos rubra (Webster)
Sigambra tentaculata (Treadwell)
Sphaerodoropsis sp.
Spio setosa Verrill
Spiochaetopterus oculatus Webster
Spionidae spp.
Spiophanes bombyx (Claparede)
Sthenelais boa (Johnston)
Sthenelais limicola (Ehlers)

Streblospio benedicti Webster
Syllidae spp.
Syllides verrilli Moore
Terebellidae spp.
ANNELIDA : OLIGOCHAETA
Oligochaeta spp.
ANNELIDA : HIRUDINEA
Hirudinea spp.
MOLLUSCA : GASTROPODA
Acteocina canaliculata (Say)
Anachis obesa Adams
Busycon carica (Montfort)
Corambella depressa Balch
Coryphella sp.
Crepidula fornicata (Linne)
Cyclostremiscus beauii (Fischer)
Cylichnella bidentata (Orbigny)
Epitonium multistriatum (Say)
Epitonium rupicola (Kurtz)
Epitonium sp.
Eupleura caudata (Say)
Gastropoda spp.
Mangelia cerina Kurtz and Stimpson
Mitrella lunata (Say)
Nassarius trivittatus (Say)
Nassarius vibex Say
Natica pusilla Say
Odostomia spp.
Polinices duplicatus (Say)
Polycera sp.
Rictaxis punctostriatus (Adams)
Turbonilla interrupta (Totten)
Turbonilla spp.
Turridae spp.
MOLLUSCA : BIVALVIA
Aligena elevata (Stimpson)
Anadara ovalis (Bruguiere)
Anadara transversa (Say)
Bivalvia spp.
Cerastoderma pinnulatum (Conrad)
Chione cancellata Linnaeus
Crassostrea virginica (Gmelin)
Ensis directus Conrad
Eucrassatella speciosa (Adams)
Gemma gemma (Totten)
Ischadium recurvum (Rafinesque)
Lyonsia hyalina Conrad
Macoma balthica Linnaeus
Macoma mitchelli Dall
Macoma tenta Say
Mercenaria mercenaria (Linne)
Mulinia lateralis (Say)
Mya arenaria Linnaeus
Mysella planulata (Stimpson)
Mytilus edulis Linne

Nucula proxima Say
Pandora bushiana Dall
Pandora trilineata Say
Parvilucinia multilineata (Tuomey and Holmes)
Siliqua costata Say
Spisula solidissima (Dillwyn)
Tellina agilis Stimpson
Yoldia limatula (Say)

ARTHROPODA : ISOPODA

Cyathura polita (Stimpson)
Edotea triloba (Say)
Erichsonella filiformis (Say)
Ptilanthura tenuis (Harger)

ARTHROPODA : AMPHIPODA

Ampelisca abdita Mills
Ampelisca vadorum Mills
Ampelisca verrilli Mills
Batea catharinensis Muller
Caprellidae spp.
Cerapus tubularis Say
Corophium spp.
Elasmopus levis Smith
Erichthonius brasiliensis (Dane)
Gammarus mucronatus Say
Leptocheirus plumulosus Shoemaker
Listriella barnardi Wigley
Listriella clymenellae Mills
Melita appendiculata (Say)
Melita nitida Smith
Parametopella cypris (Holmes)
Parapleustes aestuarius Watling and Maurer
Photis macrocoxa Shoemaker
Pleustidae sp.
Protohaustorius spp.
Stenothoe minuta Holmes
Stenothoe sp.
Synchelidium americanum Bousfield
Trichophoxus epistomus (Shoemaker)
Unciola irrorata Say
Unciola serrata Shoemaker

ARTHROPODA : CUMACEA

Cyclaspis varians Calman
Leucon americanus Zimmer
Oxyurostylis smithi Calman
Pseudoleptocuma minor (Calman)

ARTHROPODA : MYSIDACEA

Mysidopsis bigelowi Tattersall
Neomysis americana (Smith)

ARTHROPODA : DECAPODA

Callinectes sapidus Rathbun
Cancer irroratus Say
Crangon septemspinosa Say
Decapoda spp.
Euceramus praelongus Stimpson
Hexapanopeus angustifrons Benedict and Rathbun

Libinia emarginata Leach
Ogyrides limicola Williams
Ovalipes ocellatus (Herbst)
Pagurus spp.
Panopeus herbstii Milne-Edwards
Pinnixa chaetopterana Stimpson
Pinnixa cristata Rathbun
Pinnixa sayana Stimpson
Pinnotheridae spp.
Upogebia affinis (Say)
Xanthidae spp.

ARTHROPODA : PYCNOGONIDA
Pycnogonida spp.

SIPUNCULA
Phascolion strombi (Montagu)

ECHIURA
Echiura spp.

PRIAPULIDA
Priapulida spp.

PHORONIDA
Phoronis psammophila Cori

ECHINODERMATA : ASTEROIDEA
Asterias forbesii (Desor)

ECHINODERMATA : ECHINOIDEA
Arbacia punctulata (Lamarck)
Echinarachnius parma (Larmack)

ECHINODERMATA : HOLOTHUROIDEA
Holothuroidea spp.
Leptosynapta inhaerens (Ayres)

ECHINODERMATA : OPHIUROIDEA
Ophiuroidea spp.

HEMICHORDATA
Saccoglossus kowalewskii (Agassiz)

CHORDATA : CEPHALOCHORDATA
Branchiostoma virginiae Hubbs

CHORDATA : UROCHORDATA
Cnemidocarpa mollis (Stimpson)

END

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